



Calhoun: The NPS Institutional Archive
DSpace Repository

Theses and Dissertations

1. Thesis and Dissertation Collection, all items

2002-06

Realistic airspace simulation through the use of visual and aural cues

Thien, Robert E.

Monterey, California. Naval Postgraduate School

<http://hdl.handle.net/10945/5831>

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the United States.

Downloaded from NPS Archive: Calhoun



<http://www.nps.edu/library>

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

REALISTIC AIRSPACE SIMULATION THROUGH THE
USE OF VISUAL AND AURAL CUES

by

Robert E. Thien

June 2002

Thesis Advisor:

Rudolph P. Darken

Co-Advisor:

Joseph A. Sullivan

Approved for public release; distribution is unlimited.

THIS PAGE INTENTIONALLY LEFT BLANK

| | | | | |
|--|--|---|---|---|
| REPORT DOCUMENTATION PAGE | | | Form Approved OMB No. 0704-0188 | |
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503. | | | | |
| 1. AGENCY USE ONLY (Leave blank) | | 2. REPORT DATE June 2002 | | 3. REPORT TYPE AND DATES COVERED Master's Thesis |
| 4. TITLE AND SUBTITLE Realistic Airspace Simulation Through the use of Visual and Aural Cues | | | 5. FUNDING NUMBERS | |
| 6. AUTHOR (S) Robert E. Thien, Major USMC | | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000 | | | 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER | |
| 11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the U.S. Department of Defense or the U.S. Government. | | | | |
| 12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited | | | 12b. DISTRIBUTION CODE | |
| 13. ABSTRACT (maximum 200 words) The increase in air traffic volume within the National Airspace System has prompted the Federal Aviation Administration to explore more efficient methods of conducting Air Traffic Control. Toward this end, a project to develop Simultaneous Non-Interfering (SNI) Routes for rotary wing aircraft has been undertaken. In order to develop these routes with an appropriate level of safety, the ability of a rotary wing pilot to fly an assigned path with the aid of Global Positioning System navigational equipment must be evaluated. This evaluation must be conducted initially in a simulated environment. So as to record the most accurate human performance data possible, the simulated airspace must be as close to reality as possible. The goal of this thesis is to accurately simulate the airspace for use in the development of SNI routes. In order to create a realistic simulated flying environment the performance and visual presentation of other air traffic was made to perform as they do in the real world. In addition, the radio transmissions heard by the simulator pilot were designed with both timeliness and accuracy with regard to the air traffic scenario. Through the use of these visual and aural cues, a realistic airspace simulation was created. | | | | |
| 14. SUBJECT TERMS Simulated Airspace, Visual and Aural Cues | | | 15. NUMBER OF PAGES 59 | |
| | | | 16. PRICE CODE | |
| 17. SECURITY CLASSIFICATION OF REPORT Unclassified | 18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified | 19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified | 20. LIMITATION OF ABSTRACT UL | |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

**REALISTIC SIMULATED AIRSPACE THROUGH
THE USE OF VISUAL AND AURAL CUES**

Robert E. Thien
Major, United States Marine Corps
B.A., University of Colorado, 1991

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

**NAVAL POSTGRADUATE SCHOOL
June 2002**

Author: Robert E. Thien

Approved by: Rudolph P. Darken
Thesis Advisor

Joseph A. Sullivan
Co-Advisor

Christopher S. Eagle
Chairman, Department of Computer Science

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The increase in air traffic volume within the National Airspace System has prompted the Federal Aviation Administration to explore more efficient methods of conducting Air Traffic Control. Toward this end, a project to develop Simultaneous Non-Interfering (SNI) Routes for rotary wing aircraft has been undertaken. In order to develop these routes with an appropriate level of safety, the ability of a rotary wing pilot to fly an assigned path with the aid of Global Positioning System navigational equipment must be evaluated. This evaluation must be conducted initially in a simulated environment. So as to record the most accurate human performance data possible, the simulated airspace must be as close to reality as possible. The goal of this thesis is to accurately simulate the airspace for use in the development of SNI routes. In order to create a realistic simulated flying environment the performance and visual presentation of other air traffic was made to perform as they do in the real world. In addition, the radio transmissions heard by the simulator pilot were designed with both timeliness and accuracy with regard to the air traffic scenario. Through the use of these visual and aural cues, a realistic airspace simulation was created.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

| | | |
|------|---|----|
| I. | INTRODUCTION..... | 1 |
| A. | PROBLEM STATEMENT..... | 1 |
| B. | OBJECTIVES..... | 1 |
| C. | THESIS ORGANIZATION..... | 2 |
| II. | HISTORY AND BACKGROUND..... | 5 |
| A. | TERMINAL AREA AIR TRAFFIC CONTROL..... | 5 |
| 1. | Current State of Air Traffic Management..... | 5 |
| 2. | The Problem..... | 5 |
| B. | SIMULTANEOUS NON-INTERFERING ROUTES..... | 7 |
| 1. | FAA Initiative..... | 7 |
| 2. | Potential Benefits..... | 7 |
| 3. | Development of SNI Routes..... | 8 |
| a. | <i>Flight Path Adherence</i> | 9 |
| b. | <i>Simulation</i> | 9 |
| C. | CHAPTER SUMMARY..... | 14 |
| III. | IMPLEMENTATION..... | 17 |
| A. | TERMINAL ENVIRONMENT AIR TRAFFIC CONTROL..... | 17 |
| 1. | Controlled Airspace..... | 17 |
| a. | <i>Class D Airspace</i> | 17 |
| b. | <i>Traffic Patterns</i> | 18 |
| c. | <i>Traffic Handling</i> | 22 |
| B. | AIRSPACE SIMULATION..... | 24 |
| 1. | Methods..... | 24 |
| 2. | Model Design..... | 25 |
| a. | <i>Airspace</i> | 25 |
| b. | <i>Traffic Patterns</i> | 27 |
| c. | <i>Aircraft</i> | 29 |
| d. | <i>Visual Realism</i> | 30 |
| e. | <i>Auditory Realism</i> | 31 |
| 3. | Using the Application..... | 32 |
| a. | <i>Starting Points</i> | 32 |
| b. | <i>Air Traffic Control Input</i> | 34 |
| c. | <i>Tailoring the Scenario</i> | 35 |
| C. | CHAPTER SUMMARY..... | 35 |
| IV. | CONCLUSIONS..... | 37 |
| A. | GENERAL CONCLUSIONS..... | 37 |
| B. | FUTURE WORK..... | 37 |
| C. | APPLICABILITY TOWARD THE FAA'S SNI PROJECT..... | 39 |
| 1. | Simulated Airspace Requirements..... | 39 |
| 2. | SNI Flight Path Variation..... | 40 |

| | |
|---------------------------------|----|
| LIST OF REFERENCES..... | 41 |
| INITIAL DISTRIBUTION LIST | 43 |

LIST OF FIGURES

| | | |
|-----------|---|----|
| Figure 1. | Class D Airspace | 15 |
| Figure 2. | Typeical Airport Traffic Pattern | 17 |
| Figure 3. | Straight-in Approach | 18 |
| Figure 4. | Downwind Entry | 18 |
| Figure 5. | Crosswind Entry | 18 |
| Figure 6. | Overhead Procedure | 18 |
| Figure 7. | Traffic Patterns in Simulated Airspace | 26 |
| Figure 8. | Screenshot of Recommended Simulation Start Point | 33 |
| Figure 9. | Screenshot of Well Developed Traffic Scenario ... | 34 |

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

| | | |
|----------|---|----|
| Table 1. | Pattern Altitudes | 25 |
| Table 2. | Aircraft Types and Assigned Patterns..... | 28 |

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGEMENT

The time and effort that went into this thesis are a true indicator of the amount of patience and understanding possessed by my wife Emilia. I can't thank her enough for all the support that she has given me during my time in school.

I also want to thank my children Derek and Diana, for their uncanny ability to bring me back down to earth through a simple comment or action, demonstrating clearly to me what is truly important in life.

My thanks also go out to my thesis advisor, Rudy Darken and Joe Sullivan, the co-advisor of my thesis. Their knowledge and insight were instrumental in focusing and directing the topic for my thesis.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. PROBLEM STATEMENT

The National Airspace System (NAS) has experienced a steady seven to eight percent increase in the volume of air traffic for the past decade. The projection for future growth is that the rate of annual increase will remain constant. (Ref [1]) Currently the percentage of flight delays evaluated as volume delays comprises nearly one half of all non weather delays recorded in the NAS. (Ref [7]) The problem of flight delays is more than just one of inconvenience. The presence of flight delays has an economic factor due to the fact that delays invariably cost money. In some cases delays are even more costly when one considers the delay of aircraft on lifesaving missions. As the volume of traffic continues to increase, to maintain the status quo in how air traffic is handled will quickly transform the problem of congested terminal area airspaces into situations where safety is compromised. The prohibitive cost of building more airfields has precluded this as a viable solution to the problem. The burgeoning technologies in navigation to include The Global Positioning System (GPS) are being under-utilized with regard to the NAS. The current procedures in place within the NAS are based upon navigational equipment accuracy that has been far outpaced by current technology.

B. OBJECTIVES

The objectives of this thesis is to develop an airspace simulation with a high degree of realism for the purpose of providing the environment for the testing

required in the development of Simultaneous Non-Interfering (SNI) routes. SNI routes will use GPS navigation equipment in rotary wing aircraft to arrive at or depart airfields or transition through airspace while operating much closer to fixed wing arrival and departure routes than is currently allowed under FAA regulations. Once implemented SNI routes will allow the simultaneous operations of dissimilar aircraft at the same airfield and in close proximity, thus eliminating a large cause of air traffic delays. The focus of this thesis is on creating a simulated airspace with realistic simulated aircraft flying in a manner consistent with real world flight performance. Additionally this thesis aims to provide realistic voice communications in the simulated environment that are consistent with radio transmissions that take place between Air Traffic Control personnel and pilots conducting flight operations in terminal environment airspaces.

C. THESIS ORGANIZATION

The second chapter of this thesis concentrates on the history and background of the current procedures of air traffic management in terminal environments and a potential solution. The project to develop SNI routes is evaluated in regard to the potential advantages and what the development process will entail.

Chapter III breaks down the basic procedures of air traffic control in terminal environments. This level of knowledge is necessary in order to evaluate the realism of the simulated airspace. Once the base level knowledge is introduced, the specifics of the simulated airspace are

presented. The chapter concludes with the C++ code that creates the simulation.

Chapter IV considers the future applicability of the simulation. The manner in which the simulation could be used toward the development of SNI routes is presented. Methods of determining the effectiveness of the simulation in regard to realism are introduced.

THIS PAGE INTENTIONALLY LEFT BLANK

II. HISTORY AND BACKGROUND

A. TERMINAL AREA AIR TRAFFIC CONTROL

1. Current State of Air Traffic Management

The current ATC procedures in use for the management of simultaneous operations of fixed wing and rotary wing traffic in terminal environments is less than optimal. The reliance on distance separation is based on rules established many years before the advent of the highly precise navigational equipment available on most aircraft today. The result of this outdated separation criteria is a less efficient use of airspace than is possible with current technology.

2. The Problem

The continually expanding volume of air traffic worldwide has served to exacerbate the bottleneck of in-flight traffic in terminal environments. The current regulations for aircraft separation, specifically in regard to simultaneous rotary and fixed wing operations in terminal environments were developed when the volume of air traffic was not as robust and when the state of navigational precision, from both electronic navigational equipment and flight control systems, required a relatively large safety buffer to be calculated into the separation criteria. The problem created by suboptimal handling of air traffic in terminal environments is twofold. The first part of the problem is fiscal. The extra time spent in the air represents money lost by the aircraft operator in the form of extra fuel having to be burned. This fiscal issue is of real concern to an industry that as a general rule

operates close to the margin. The second part of the problem is that of wasted time. The issue of wasted time spent airborne has a dual nature as well. In order to maximize their use of the aircraft in their fleet, commercial airlines operate under an aggressive time schedule. The result of unexpected delays due to the simultaneous handling of rotary and fixed wing aircraft is the disruption of the commercial airline schedule. Due to the volume of air traffic and the aggressive scheduling these delays can be propagated quickly throughout the National Airspace System (NAS). The other aspect of the problem with wasted time is the nature of some of the rotary wing operations. The use of rotary wing aircraft for medical emergency missions (Lifeflight) is widespread. It is often the case that a rotary wing aircraft on a medical emergency mission in a metropolitan area will need to fly through a terminal airspace. Even though a Lifeflight aircraft will be given priority handling through a terminal environment, based on the current traffic scenario, some delays will be experienced by the Lifeflight aircraft due to the requirement to safeguard all aircraft. An example of this is that a jumbo jet on a short final approach can't simply disappear because of the sudden presence of a Lifeflight needing to cross the extended centerline of the runway. Another cause for Lifeflight delay is the presence of wake turbulence. Wake turbulence is the spirals of turbulent air that extend downward and outward behind an aircraft and are much more severe from larger aircraft. There are a multitude of causes for delays for all aircraft in a terminal environment. The unnecessary delays resulting from obsolete regulations or

the non-use of current technology are areas that should be reviewed for the purpose of maximizing the flow of air traffic.

B. SIMULTANEOUS NON-INTERFERING ROUTES

1. FAA Initiative

The FAA has initiated a proposal to investigate the development of Simultaneous Non-Interfering (SNI) flight within the NAS. SNI flight by definition would override the separation criteria normally associated with rotary wing flight within a terminal environment. The FAA's initiative would take advantage of The Global Positioning System (GPS) and the inherent flight characteristics of rotary aircraft, those of slow flight and high maneuverability.

2. Potential Benefits

The implementation of SNI routes into the NAS could potentially result in an immediate positive impact to the safety and economics of air flight. The overall volume of traffic in terminal environments could be increased by allowing the simultaneous operations of rotary and fixed wing aircraft. Concurrently the chances of a mishap could be significantly decreased through the logical development of the SNI routes so as not to interfere with the normal flow of arrival and departure fixed wing aircraft. Although the airspace of a terminal environment can be a busy place, there is more airspace that is not used than is used. This fact coupled with the high maneuverability of rotary wing aircraft presents a vast untapped resource. The safety factor is evident by not requiring the mixing of the slower and smaller rotary wing aircraft with the

larger and faster fixed wing aircraft. Ideally the rotary wing aircraft would not even use the same landing surface as the fixed wing aircraft (i.e. the use of landing pads or surfaces separate from the established runways). The economic benefit is self evident. More passengers and cargo that can arrive or depart from a location in the same amount of time represents an economic boon. There is also a cost saving factor involved with SNI routes. Fewer delays due to incompatible traffic equates to less time in the air and less money spent on fuel. Time saving also will benefit, as not all SNI routes need to terminate at a landing surface. The concurrent development of SNI routes to transition through a terminal environment airspace would benefit Lifeflight aircraft specifically, but all aircraft in general.

3. Development of SNI Routes

It is quite clear that the development of SNI routes will bring many benefits. The more daunting task is where to put SNI routes or more precisely within what proximity to established fixed wing traffic corridors can SNI routes be placed. This leads to another question which is whether or not SNI routes will be strictly for Visual Meteorological Conditions (VMC) or for both VMC and Instrument Meteorological Conditions (IMC). VMC are meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling equal to or better than specified minima. (Ref.[2]) Flying under VMC conditions is called flight under Visual Flight Rules (VFR). IMC are meteorological conditions expressed in the same terms as VMC but that are less than specified minima for VMC. Flight under IMC conditions is called flight under

Instrument Flight Rules (IFR). For the case of IFR SNI routes the proximity of these routes to established fixed wing flight corridors becomes a function of the accuracy of the Global Navigation Satellite System (GNSS) and the ability of qualified pilots to adhere to the SNI route. There will naturally be a margin for error factored in to the development of SNI routes, but what is the margin of error? In order to make SNI routes effective and safe, the margin for error must be more strict than for the traditional airways within the NAS. Airways (V-routes and J-routes), which are the primary navigational routes within the NAS, are established as two mile wide corridors. The margin for error afforded to pilots navigating an airway would not be acceptable for a SNI route in a terminal environment.

a. Flight Path Adherence

The first step in developing SNI routes is to compare the use of GPS navigation to visual navigation for pilots of rotary wing aircraft to determine if a significant reduction in flight path variation can be achieved. The ability of a pilot to adhere strictly to an established flight path with a small amount of variation is the keystone that SNI routes will be built on. In the absence of strict flight path adherence, SNI routes would introduce a potentially hazardous variable to already highly congested terminal environment airspaces.

b. Simulation

It isn't feasible for flight path adherence (FPA) testing to be conducted in a live flight scenario, at least not in the early stages of SNI route development. The

safety of the airspace could be compromised. In addition the type of data that needs to be recorded would be difficult to accomplish inside a rotary wing aircraft. There are many factors which need to be considered and adjusted during the FPA testing. The main piece of data to be collected is the ability of the pilot to adhere to the assigned path. However, other factors can be manipulated which could result in a greater ability to fly the assigned flight path. Through the use of eye tracking technology and by measuring the head movement of the pilot the placement of the GPS navigation device within the cockpit can be adjusted to produce the best pilotage. In addition the presentation of the GPS navigation display itself can be altered in further efforts to improve FPA. Through the use of eye tracking technology, it can be determined where the pilot is looking and the duration and frequency of his gaze on any object. The eye tracking results can be compared against the Flight Path Adherence data and changes may be implemented in the placement or display of the GPS navigational equipment. The ability to quantify and decipher pilot eye fixation will illustrate to what extent the use of GPS navigation will aid in the development of SNI routes. These are just a few of the multitude of human performance factors that will need to be measured and adjusted in the effort to maximize the pilots ability to fly the assigned route. The sheer number of variables make live flight testing unfeasible.

The conundrum presented now is that FPA must be tested in a simulated environment but for reasons that are all too obvious, there must be few or no artificialities in the simulation.

The necessity of simulating accurately the pilot interface (the flight controls) and the airframe performance characteristics are also quite apparent. The realism however must be taken down to the smallest detail to ensure the safety of the eventual real world use of SNI routes. There are a great many flight simulators on the market today and there are some that have accurate flight control and airframe performance characteristics. However, the aspect of realism that is missing from these simulators is the accurate representation of distractions to a pilot that are present in a congested terminal environment.

The ability of a pilot to achieve a high degree of Flight Path Adherence in a sterile environment is worthless for use in a real world environment. In order to develop safe and efficient SNI routes, the level of FPA required must be at a level that is achievable in the presence of all the distractions to pilotage in the real world. Once implemented, SNI routes will be navigated in the midst of well developed terminal air traffic environments. Therefore, during development, the manipulation of all the variables associated with SNI routes (proximity to other aircraft, speed, altitude, degree of turns, etc.) must be conducted under realistic simulated conditions. Once a pilot has mastered the ability to fly his own aircraft then the greatest danger to him is the presence of other aircraft in the sky. The most hazardous area in which to operate an aircraft is in a terminal environment due to the fact that a pilot won't experience such a large number of aircraft all operating in a small space anywhere else in the sky. In order to simulate a terminal environment for pilotage testing

purposes these factors must be included. That is the presence of other air traffic must be a part of the simulation.

Achieving a high degree of realism in a terminal environment simulation is where current flight simulators fall short. The key to achieving realism is in paying attention to the details. One small detail in a simulation can potentially skew the results of the testing. A pilot has many factors to focus on while in the air. Aside from piloting his own aircraft, a pilot's concern is focused on other aircraft in the air (visually) and information gathered from radio transmissions (aurally). If either one of these aspects of a simulation is deemed to be artificial by the pilot in the flight simulator then a realistic focus by the test subject on that aspect will not be achieved. The presence of artificialities in the simulation can cause the pilot to "play" the simulator, which will invalidate the human performance data that is collected. The resulting lack of focus on one aspect will permit an unconscious and unrealistic shift away from one aspect to allow more and unrealistic attention to other aspects, thereby skewing the results of the test.

Consider the case of an experienced pilot conducting a Flight Path adherence simulation in a simulated terminal environment. The pilot will begin the simulation using his own normal eye scan pattern. An eye scan pattern is an implementation of aircraft pilot multi-tasking. This regimented shift of focus enables a pilot to keep updated on all flight variables, which include not only a multitude of instruments and readouts in the cockpit

but also other aircraft in his local vicinity. Another variable included in the multi-tasking problem presented to a pilot is the necessity of listening to radio transmissions. Radio transmissions directed to the pilot will be prefaced with his aircraft's call sign, so he will have a cue when a transmission pertains directly to him.

However, especially while operating in a terminal environment, due to the high volume and density of air traffic, a pilot will glean information from every transmission. This information will come both from Air Traffic Control and from other pilots. The pilot will continually process aural information and relate that information to visual cues (other aircraft). In order to safeguard his own aircraft a pilot in a terminal environment becomes an air traffic observer. While certainly not responsible for controlling all the aircraft in the airspace as an Air Traffic Controller is, the pilot is aware of the intentions and actions of all the aircraft in the airspace. In this way the pilot should not be surprised by the actions of other aircraft and can continually update the terminal airspace scenario mentally.

This example serves to illustrate one of the distractions to pilotage that are present in a terminal environment. In the simulated scenario, realism can only be attained if these distractions both visual and aural are presented realistically. If other simulated aircraft don't fly in a manner consistent with the flight specifications for that type of aircraft or they don't adhere to the airspace's traffic patterns then the value of the other simulated aircraft as realistic distractions is lost.

Similarly, if radio transmissions, don't follow the FAA phraseology or if they are artificial in timing or content, then the value of the aural distraction is lost for the simulation.

Once the integrity of realistic distraction is broken then the pilot flying the simulator will alter his eye scan pattern and alter his reaction to radio transmissions received. Once this happens the percent of mental focus directed towards pilotage increases to an unrealistic level and the pilotage results will not reflect a realistic result.

The airspace simulation project presented with this thesis focuses on achieving realistic distractions. The value of a realistic airspace simulation as the foundation for developing SNI routes is extremely high. The mission of Air Traffic Control is "The safe, orderly, and expeditious flow of air traffic" (Ref[2]). The achievement of this mission as it relates to the development of SNI routes requires that the starting point be a realistic (in all aspects) terminal environment airspace simulation.

C. CHAPTER SUMMARY

The volume of air traffic present in the National Airspace System is constantly growing and this increase is most evident in terminal environments. The current procedures for handling a mixture of fixed wing and rotary wing air traffic is less than optimal. The capabilities of current navigational technology coupled with the unique flight characteristics of rotary wing aircraft present the possibility of developing Simultaneous Non-Interfering

Routes in and through terminal environment airspace. The implementation of SNI routes would be greatly beneficial both in terms of flight safety and in economic terms.

The FAA has proposed the development of SNI routes. Before these routes can be developed the ability of a rotary wing pilot to adhere to a designated path through the use of GPS navigational equipment must be determined. Through this determination, the placement of SNI routes at a safe distance from fixed wing flight corridors can be established. In order to accurately determine the ability of rotary wing pilots to adhere to a designated path, a realistic terminal environment airspace simulation must be developed. This simulation must be realistic in all aspects, especially in terms of distractions to pilotage (i.e. other aircraft in the airspace and radio transmissions).

THIS PAGE INTENTIONALLY LEFT BLANK

III. IMPLEMENTATION

A. TERMINAL ENVIRONMENT AIR TRAFFIC CONTROL

1. Controlled Airspace

Controlled airspace is an airspace of defined dimensions within which air traffic control service is provided to IFR flights and VFR flights in accordance with the airspace classification. Controlled airspace is a generic term that covers Class A, B, C, D, and E airspace. Controlled airspace is also defined as that airspace within which all aircraft are subject to certain pilot qualifications, operating rules, and equipment requirements as delineated in the appropriate Code of Federal Regulations (CFR Part 91). For IFR operations in any class of controlled airspace, a pilot must file and IFR flight plan and receive an appropriate ATC clearance. Each Class B, C, and D airspace area designated for an airport contains at least one primary airport around which the airspace is designated.(Ref[2])

a. Class D Airspace

The simulated airspace for this project is Class D airspace (Figure 1). The reasons behind choosing class D airspace for the simulation will be presented in a later section following the explanations of the procedures and details of this type of airspace. Class D airspace is defined as that airspace from the surface to 2,500 feet above the airport elevation (charted in MSL) surrounding those airports that have an operational control tower. The configuration of each Class D airspace area is individually tailored and when instrument procedures are published, the

airspace will normally be designed to contain the procedures. Arrival extensions for instrument approach procedures may be Class D or Class E airspace. Unless otherwise authorized, each person must establish two-way radio communications with the ATC facility providing air traffic services prior to entering the airspace and thereafter maintain those communications while in the airspace. No separation services are provided to VFR aircraft.(Ref[6])

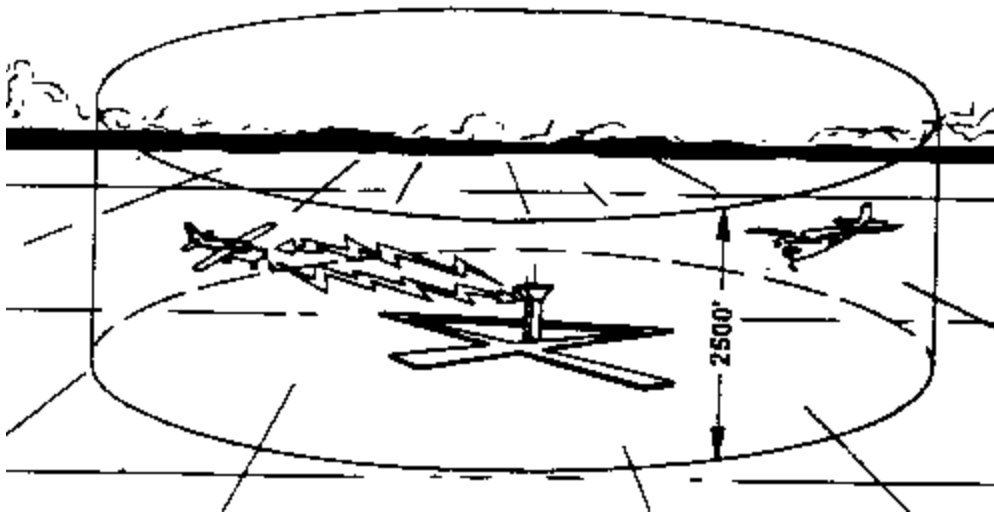


Figure 1. Class D Airspace (Ref[5])

b. Traffic Patterns

The traffic patterns and flow of traffic is different from one Class D airspace to the next. By definition the dimensions of one Class D airspace differ from another as well (with the exception of the ceiling altitude in reference to the airfield elevation). The diameter of the airspace will be established as large enough to contain the flight procedures that are in place at the airfield. In general traffic patterns will be

established that are similar from one Class D airspace to another.

(1) Duty Runway. The runway in use or duty runway is determined by the direction and velocity of the wind at the airfield. In the case of a calm wind (less than 5 knots) the duty runway will be chosen by the control tower based on established noise abatement procedures. For winds of 5 knots or greater, the runway with the greatest headwind component will be chosen. Based on the duty runway, the active traffic patterns for the airspace will be determined.

(2) Patterns. Traffic patterns will be similar in any Class D Airspace. A standard traffic pattern is roughly oval in shape and is sometimes referred to as a racetrack pattern. The direction of turns for the aircraft determine whether it is referred to as left hand or right hand traffic. The figure below (Figure 2) is an example of left

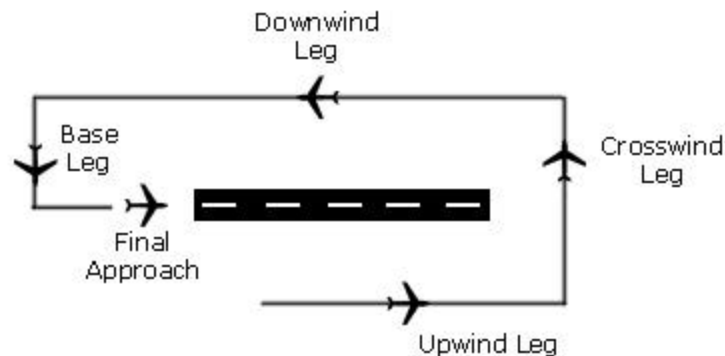


Figure 2. Typical Airport Traffic Pattern from (Ref[4])

hand traffic. Several traffic patterns will be stacked on top of each other separated by 500 feet. These altitude separated patterns will each be designated for a particular type of aircraft based on performance and speed. A typical airfield would have a rotary wing pattern at 500 feet Above Ground Level (AGL), another pattern for propeller driven aircraft at 1000 feet AGL, a third pattern for jet aircraft at 1500 feet AGL, and a final pattern for the military overhead procedure at 2000 feet AGL.

(3) Pattern Entry Procedures. Part of the complexity of air traffic control and in navigating safely through a terminal environment airspace is the fact that aircraft will enter the airspace and traffic patterns from all different directions. The simplest entry is a straight in approach (Figure 3). Another common approach is the downwind entry (Figure 4) in which the arriving aircraft enters the pattern on the downwind leg. A cross wind entry (Figure 5) is when the aircraft crosses over the airfield at pattern altitude and turns onto the downwind leg or simply enters the crosswind leg. The last type of approach is the military overhead procedure (Figure 6) which begins like a straight-in approach, flies over the runway at the overhead altitude and then uses the remainder of the racetrack pattern to lose speed and altitude.



Figure 3. Straight-in Approach



Figure 4. Downwind Entry

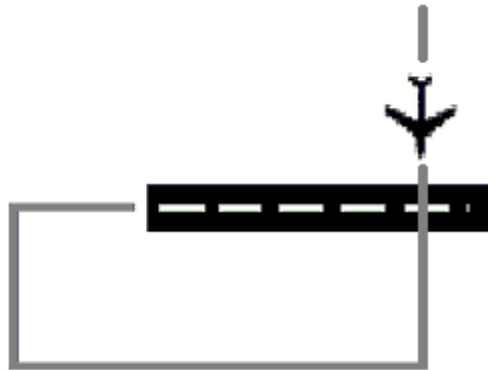


Figure 5. Crosswind Entry



Figure 6. Overhead Procedure

c. Traffic handling

(1) ATC Duties. The primary purpose of the ATC system is to prevent a collision between aircraft operating in the system and to organize and expedite the flow of traffic. In addition to its primary function, the ATC system has the capability to provide (with certain limitations) additional services. The ability to provide additional services is limited by many factors, such as the volume of traffic, frequency congestion, quality of radar, controller workload, higher priority duties, and the pure physical inability to scan and detect those situations that fall in this category. (Ref[2])

(2) Procedures. Before entering a Class D airspace and at all times while operating within the airspace, a pilot must be in constant two-way communication with the control tower. The control issues all clearances for operations such as take-off, landing, touch and go, etc. Another duty of the air traffic controller is to issue traffic calls, as there are often a large volume of aircraft operating simultaneously within the airspace the traffic call is an invaluable tool for the controller and the pilot.

(3) Duty Priority. First priority is given to separating aircraft and issuing safety alerts as required. Good judgment shall be used in prioritizing all other duties based on the requirements of the situation at hand. Because there are many variables involved, it is virtually impossible to develop a standard list of duty

priorities that would apply uniformly to every conceivable situation. Each set of circumstances must be evaluated on its own merit and when more than one action is required, controllers shall exercise their best judgement based on the facts and circumstances known to them. That action which is most critical from a safety standpoint is performed first. Additional services are provided to the extent possible, contingent only upon higher priority duties and other factors including limitations of radar, volume of traffic, frequency congestion, and workload. (Ref[3])

(4) Operational Priority. Air traffic control services are provided on a "first come, first served" basis. An aircraft conducting IFR flight does not have priority over a VFR flight due simply to the nature of its flight plan. An IFR aircraft may have to adjust its flight path in order to enter a traffic pattern with arriving VFR aircraft. There are exceptions to the "first come, first served" guideline. An aircraft in distress has the right of way over all other air traffic. Priority is also given to air ambulance flights using the call sign "LIFEGUARD". The use of this call sign indicates a request for priority handling.

(5) Sequencing. The safe, orderly, and expeditious flow of air traffic in a terminal environment is accomplished by the air traffic controller through sequencing. Sequencing is the arranging of aircraft operating in the airspace in a logical manner in order to provide for enough spacing between aircraft to maintain safety. Sequencing of aircraft is carried out with the

knowledge of each aircraft's performance characteristics and the pilot's intentions.

(6) Phraseology. There is a standard phraseology used by Air Traffic Control when issuing instructions or clearances. In order to safeguard against misunderstandings between pilot and controller and to prevent the need to repeat transmissions due to vagueness of language, a standard set of phraseology was developed that is used by all controllers.

B. AIRSPACE SIMULATION

1. Methods

The airspace simulation was built as a Vega application. Vega is a high performance visual simulation system developed by MultiGen-Paradigm. The Vega software development environment is an industry-leading application for realtime visual simulation enabling the efficient development of comprehensive realtime simulations. (Ref[5]) Vega is a system that can be used to construct a simulation application quickly, with the highest performance possible. To accomplish this, Vega includes LynX, a graphical interface that provides the ability to construct the bulk of an application in a point and click environment. LynX generates an Application Definition File (ADF) that is used to configure the application. The ADF in which the simulated airspace was created, was used in conjunction with C++ code in order to add the additional aspects of realism this project sought to achieve.

2. Model Design

The FAA project to investigate the development of SNI routes is in its infancy and for that reason a real world airspace has not been chosen as the basis for their testing. For that reason a fictitious airspace with a generic airfield arrangement was created for this project. The primary criteria for developing the simulated airspace was not the airfield layout, but rather the presence of realistic simulated aircraft and radio transmissions. The layout of the airfield does govern, to a large extent, the traffic patterns available in an airspace. However, for purposes of creating a realistic airspace through which the pilot of a rotary wing aircraft can navigate, the airfield design is irrelevant so long as the traffic patterns and the aircraft on those patterns behave in a realistic fashion. The other aspect of realism that this project seeks to achieve, that of realistic auditory distractions to pilotage, is independent of airfield layout other than restricting the sheer volume of transmissions. This one restrictive point can easily be overcome by adjusting the volume and complexity of the simulated air traffic.

a. Airspace

The type of airspace chosen for this simulation was Class D. Although a Class B or C airspace would allow the model to simulate one of the major airports in the NAS, Class D airspace allows a higher degree of freedom for manipulating the flight of other aircraft and still maintaining a high degree of realism. The volume of air

traffic in a Class D airspace is significantly less than the other two types of terminal environments.

However, it is very realistic to experience the entire range of arrival and departure flight profiles. Whereas in real world Class B or C airspaces, due to the heavy volume of air traffic there is little more than straight in arrivals and straight out departures. In addition, the presence of aircraft conducting multiple practice approaches in Class D airspace is commonplace. Practice approaches, which are the activity of an aircraft that enters the pattern to conduct a low approach or a touch and go, followed by a repeat of the same, are very rarely seen in Class C or B airspaces. Most heavy use airfields allow only straight-in full stops and departures.

By using a Class D airspace for the simulation, a more dynamic and challenging air traffic scenario was developed. The level of complexity of air traffic is scaleable to allow variance in simulation scenarios. The goal was to create an environment in which a high volume of air traffic with multiple flight and pattern profiles were present in a limited size of airspace in order to create the most dynamic visual distractions to pilotage while maintaining a high degree of realism.

For these reasons the simulated airspace is a Class D airspace supporting a single runway (runway 3/21) which is 5577 feet long x 196 feet wide. The airfield elevation is set at 0 Mean Sea Level (MSL). The ceiling of the airspace is 2500 feet Above Ground Level (AGL) and the diameter of the airspace is five Nautical Miles (NM).

b. Traffic Patterns

In order to create a dynamic traffic environment possible, all the traffic patterns are in use by the simulated aircraft. The duty runway for the simulation is runway 3 and the traffic pattern is right hand traffic. The pattern altitudes are described in table 1. In

| Pattern | Altitude |
|-----------------------------|-----------------|
| Rotary Wing | 500 AGL |
| Fixed Wing (propeller) | 1000 AGL |
| Fixed Wing (jet) | 1500 AGL |
| Military Overhead Procedure | 2000 AGL |

Table 1. Pattern Altitudes

addition to the standard patterns, an airspace transition profile is used to add more complexity. The pattern for an airspace transition is simply to cross through the airspace at the appropriate pattern altitude assigned to that type of aircraft. Figure 7 is a top-down depiction of the airfield and traffic patterns. So as to ensure an air Traffic scenario that can be tailored to any length of test flight by the pilot flying the flight simulator aircraft, the traffic patterns are coded to fly loops. When a simulated aircraft departs after a practice approach, the flight path will bring the aircraft back into an arrival profile. The paths that are flown take the aircraft outside of the Class D airspace.

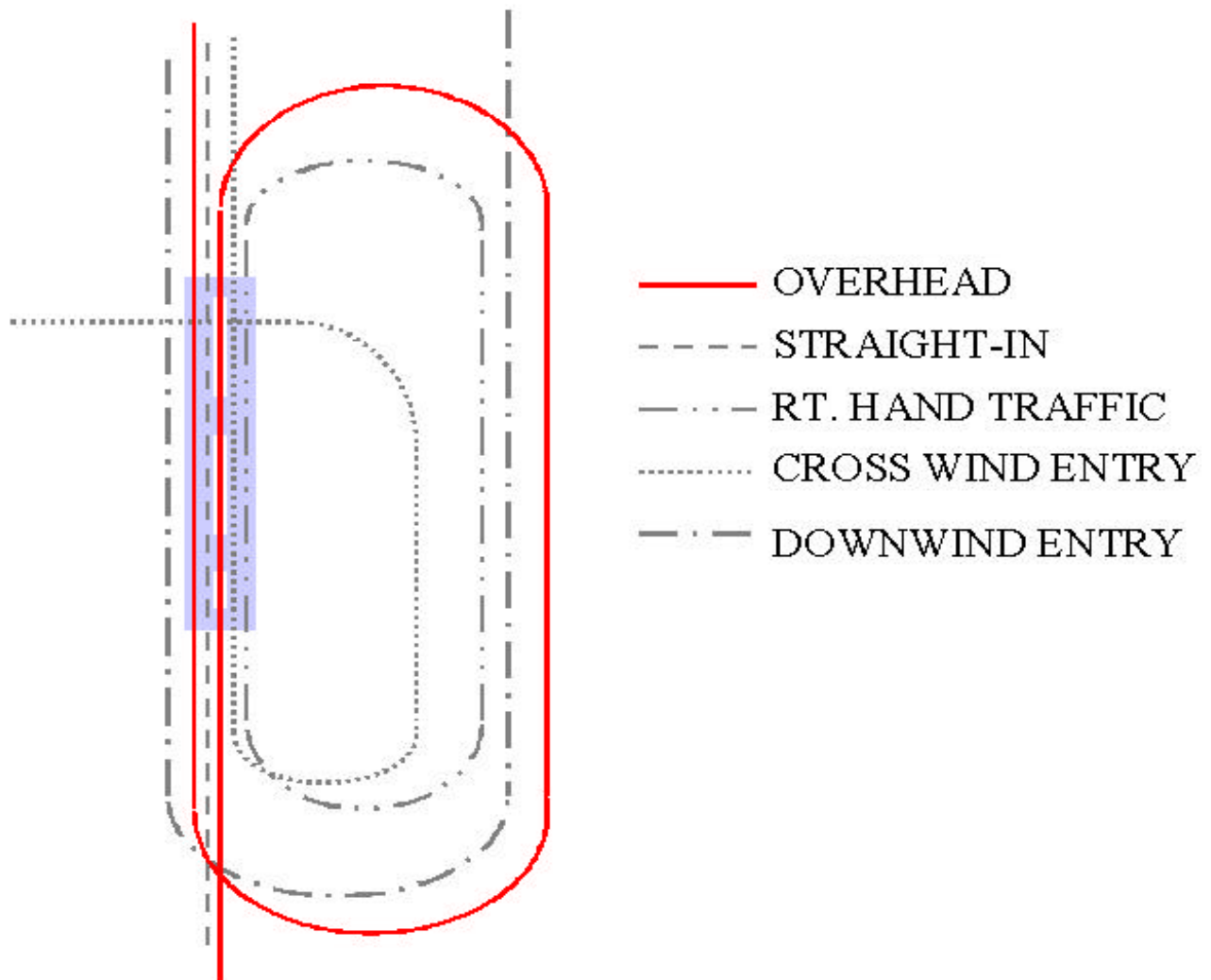


Figure 7. Traffic Patterns in Simulated Airspace

For added realism the flight profiles of the aircraft while outside the Class D airspace are consistent with the flight profiles they would have under real world conditions where they would be under the control of an Arrival/Departure Controller from a Radar Air Traffic Control Facility. The only exception to this realism is with the aircraft flying the transition pattern. In this case the simulation simply resets the aircrafts position

once it reaches the end of its path. The beginning and end of the transition path are well outside of the Class D airspace.

For the purpose of evaluating pilotage toward the development of SNI routes there is no need for the simulator pilot to fly in the vicinity of the aforementioned artificiality. This lack of realism was introduced for ease of computer code re-use and is transparent for the purpose of this simulation.

c. Aircraft

The aircraft included in the airspace simulation were chosen for their high level of common usage within the NAS. Another factor in the airframe choices was to present a variety of size and performance characteristics. Table 2 lists the aircraft type and the assigned flight patterns for each of the simulated traffic aircraft. The aircraft

| Aircraft Type | Assigned Pattern |
|----------------------|--------------------------------------|
| C-130 | Touch and Go (remain in the pattern) |
| F-15 | Overhead Procedure |
| Dash 8 | Overflight (transition) |
| DC10 | Downwind Entry |
| KC-135 | Straight-In |
| KC-130 | Crosswind Entry |
| A-10 | Touch and Go (remain in the pattern) |

Table 2. Aircraft Types and Assigned Patterns

were matched up against the type of pattern that is consistent with the type of approach they would conduct in a real world environment (e.g. the DC10 would never conduct the overhead procedure).

d. Visual Realism

The amount of realism achieved in the simulation is the gauge by which the project is viewed as a success or failure. The ability to manipulate the flight aspect variables to such a fine degree of precision through the use of LynX in the development of the simulation was instrumental in achieving realistic flight profiles for the simulated air traffic.

The flight aspect variables of heading, pitch, and roll were available for assignment and the application enabled a smooth transition during flight aspect changes. The assigned patterns were developed through the use of the "pathing tool" in LynX. The pathing tool provided the capability to establish waypoints along a path. At each waypoint the six variables of aircraft position (x, y, and z values) and orientation (heading, pitch, and roll) could be established for position. The speed could be set at a constant velocity for the current path segment (between waypoints) or the beginning and ending velocities for the current path segment could be set. For the path segments between the waypoints, the LynX pathing tool, provided the use of a spline curve to ensure a smooth curve was produced. With the aircraft performance characteristics as a reference, the pathing tool made the creation of realistic air flight possible through the careful placement

of waypoints and the precise assignment of values for each one.

e. Auditory Realism

One of the glaring artificialities in most flight simulators on the market today is the radio transmissions that are heard by the simulator pilot. Some simply have background radio transmission noise, while others have radio transmissions that one might actually hear over a radio in a terminal environment. The focus of most other flight simulators is quite dissimilar to the airspace simulation for this project. Many flight simulators are more of a video game than anything else and therefore the realism they seek is not what is needed for the development of SNI routes.

Still others are not just video games, rather they are tools used to develop the skills necessary to fly a real aircraft. Those simulators achieve their objectives admirably, but they would produce misleading results if used during the development of SNI routes as their level of realism is limited to what they tried to achieve. The radio transmissions one does hear in other simulators may indeed be real ATC phraseology, but the glaring problem is that transmissions have little relevance to the air traffic situation. In this way even real ATC instructions on these simulators become little more than annoying background chatter.

In order to achieve auditory realism, the path of all seven simulated aircraft had to be tracked and timed. With this information decisions had to be made from an Air

Traffic Control standpoint about when in the simulation different clearance or traffic advisory information would be transmitted. All the transmissions were then recorded as individual wave(WAV) files. The appropriate ATC transmissions were then set up to play at the proper time. The only transmissions that were not recorded ahead of time are those that pertain to the simulator aircraft. The simulator aircraft is a dynamic entity in the airspace simulation, that is there is no way of telling ahead of time, what traffic calls or clearance information will need to be issued to the simulator aircraft in reference to the other air traffic and vice versa.

The necessity of achieving auditory realism is equally as important as that of visual realism in the creation of a simulated airspace for the purpose of evaluating pilotage. A pilot in the real world will use radio transmissions to augment his situational awareness. The processing of this auditory input is a distraction from piloting the aircraft. The momentary shift of attention from the aircraft instruments and terrain of the environment is constantly occurring especially when a high volume of air traffic exists within the airspace.

3. Using the Application

a. Starting Points

When the simulation begins the airspace will be in the midst of an already developing air traffic scenario

as depicted in figure 8.

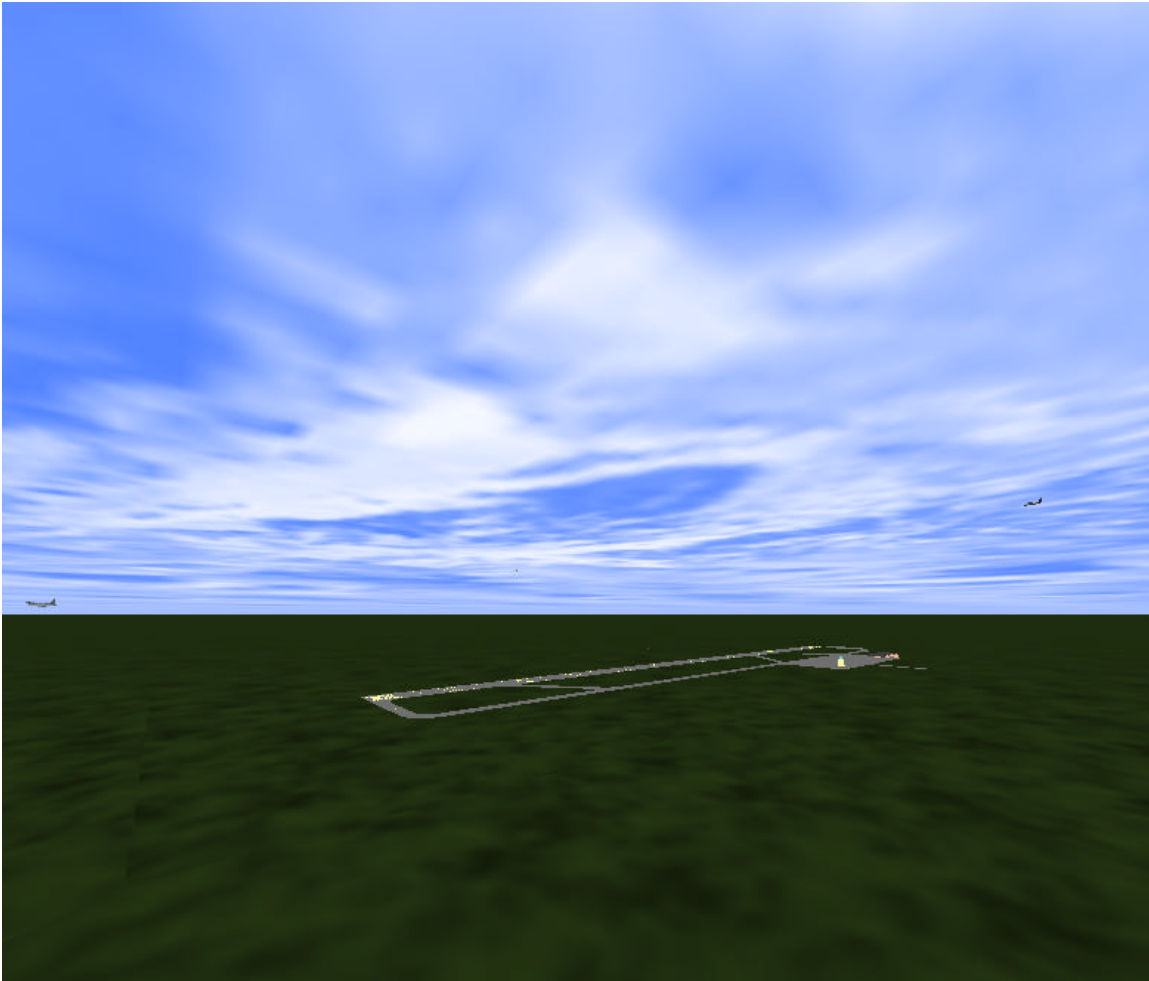


Figure 8. Screenshot of Recommended Simulation Start Point.

The maximum effectiveness of the simulation will be gained by establishing the starting point roughly North and West of the airfield. The greatest interaction with other aircraft will occur if the simulated pilot is directed to fly his aircraft in a airspace transition pattern with the goal of reaching the a point roughly South and East of the airfield. Figure 9 displays a portion of

the flight path where the traffic situation is well developed.

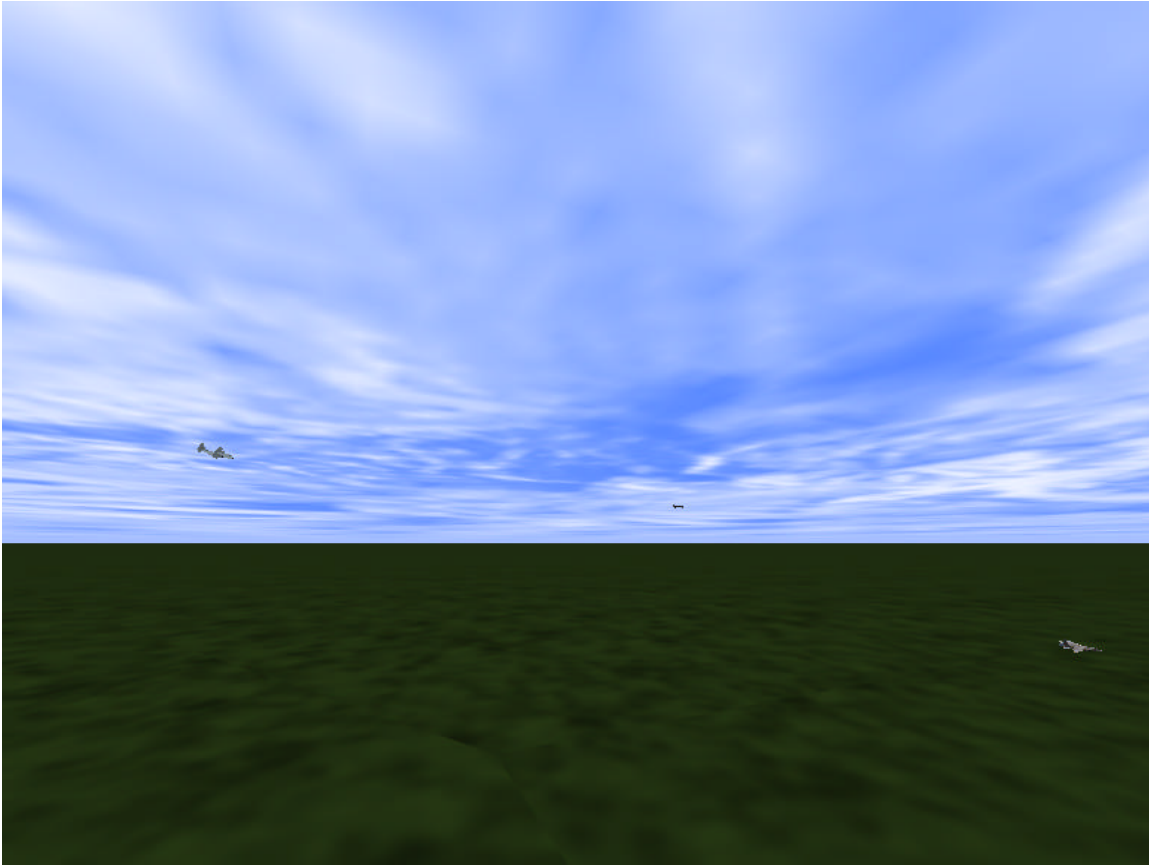


Figure 9. Screenshot of Well Developed Traffic Scenario

b. Air Traffic Control Input

Most of the radio transmissions originating from ATC or from the simulated aircraft will be carried out by the simulation. However, to achieve the desired level of auditory realism, a certain number of dynamic transmissions will need to be made based on the speed at which the simulated pilot transitions through the airspace. For this reason, to maximize the realism of the airspace the administrator of the simulation or his designee will be required to evaluate the developing air traffic scenario

and issue proper radio transmissions at the appropriate time.

It would be highly beneficial toward this end, if the person transmitting the dynamic ATC traffic calls was a qualified Air Traffic Controller. If this is not possible then alternatively someone with an extremely good working knowledge of airspace and Air Traffic Control matters could serve in this capacity.

c. Tailoring the Scenario

When the scenario begins all the simulated aircraft are active and present in the airspace. If there is a need to simplify the scenario at any time, for whatever reason, the simulated aircraft can be removed on an individual basis. The function also exists to reset all aircraft to their starting points, essentially a scenario reset button. The automated traffic calls and ATC clearances issued are tied to the presence of the aircraft in the scenario. When an aircraft is removed no more transmissions to or from the removed aircraft will be heard.

C. CHAPTER SUMMARY

The airspace chosen for this simulation is Class D airspace. It offers the most flexibility in creating a complex scenario while maintaining the level of realism required for this project. The use of Class D airspace provides the ability to create a scenario using a multitude of traffic pattern profiles and pattern entry profiles. In addition the conducting of multiple practice approaches

would only be a realistic goal within a Class D airspace. The goal in creating the airspace was to provide a scenario that would present a complex array of realistic visual distractions to the simulator pilot.

The other aspect of realism that this simulation sought to achieve was that of auditory realism. In order to simulate the attention that a real world pilot gives to ATC transmissions in a terminal environment, the simulated transmissions had to be constructed and delivered accurately for both content and situational relevance.

The realism presented in this scenario is necessary in order to simulate the one important aspect that can't be automated. That aspect is a realistic division of the simulated pilot's attention among flight control equipment, visual environmental cues (air traffic) and auditory cues (ATC transmissions). If the realism is degraded in either the visual cues or auditory cues then this simulation loses effectiveness toward the evaluation of pilotage in a congested terminal environment.

IV. CONCLUSIONS

A. GENERAL CONCLUSIONS

The airspace simulation presented in this thesis is the logical first step in developing Simultaneous Non-Interfering Routes for rotary wing aircraft. Due to the inherently hazardous nature of SNI routes the most important aspect of the airspace simulation is that the highest level of realism possible be achieved. The simulation presented provides a high degree of realism for both visual and auditory cues. The simulated airspace provides the environment for all manner of testing and evaluating that must be accomplished during the development of SNI routes.

B. FUTURE WORK

The future use of the project from this thesis is the evaluating of simulated rotary wing pilotage in a terminal environment. Evaluating pilotage is a complex issue with many opportunities for results to be skewed. The very purpose of SNI routes requires that pilotage be tested within close proximity to other standard terminal environment air traffic. The purpose of SNI routes is to provide the capability for more air operations to be conducted in a shorter amount of time through the use simultaneous operations of dissimilar aircraft with a close proximity to each other. The evaluation of pilotage will determine to what degree a rotary wing pilot can adhere to an assigned flight path through the use of GPS navigational equipment. Toward this end an analysis of the factors that

would cause the pilot to stray off course must be conducted in order to ensure those factors are included in the simulation. The following factors are deemed to be those that could contribute to pilotage errors: 1) pilot skill level, 2)GPS equipment inaccuracies, 3) distractions that draw the pilots attention away from the task of flying the correct path. Of these factors, the first two relate to the rotary wing flight simulation rather than to the airspace simulation. The flight controls used to fly the simulated helicopter must be accurate both visually and by function. The factor of GPS equipment inaccuracies will become an issue for those make the geographic decisions concerning the placement of the simulated SNI route. The third factor that contributes to pilotage error is what the airspace simulation must provide. The other aircraft in the simulation must fly according to established air traffic patterns while adhering to their airframe performance characteristics. In addition the radio transmissions that the simulated rotary wing pilot hears must be equivalent to those that would be heard in an actual terminal environment airspace.

The importance of providing realistic distractions to the pilotage is of high importance. There are several methods that could be used to validate the accuracy of the distractions to pilotage. The first is the use of eye tracking technology to map the pilot's eye scan pattern. A baseline for each test subject must be established before any simulated flying occurs. The eye movements of the pilot should be tracked while flying in a real world terminal enviroment airspace of a similar nature to the simulated airspace. The same eye movements should be

tracked for the pilot during all simulated flight time. The comparison and analysis of these results will yield the answer to whether the visual cues in the simulation served as realistic distractions to pilotage. The second method of validating the accuracy of distractions to pilotage is to measure the effectiveness of the auditory cues in the simulation. One method for testing the auditory realism is to administer a test immediately following the completion of each live flight and simulated flight. The test would require the pilot to recall the overall air traffic scenario that was present during the flight time. The pilot will be asked to recall in as much detail as possible the call signs, type of aircraft, activity of all aircraft in the airspace, and any other recollections relevant to the flight which just completed. A comparison of recall accuracy between the live and simulated flights will aid in validating the level of realism achieved by the auditory cues. In addition time coordinated recordings of all transmissions heard over the radio should be compared to the time coordinated eye tracking results. The analysis of this data will determine if the eye movements due to the content of radio transmissions were comparable in both the live and simulated flights. This result also will aid in validating the realism of the auditory cues.

C. APPLICABILITY TOWARD THE FAA'S SNI PROJECT

1. Simulated Airspace Requirements

The first step in developing SNI routes is to determine their feasibility through evaluation of rotary

wing pilotage using GPS navigation. It is impractical to conduct such evaluations in a real world environment. Therefore a simulated environment must be used. Due to the high risk nature of air flight in terminal environments the level of realism required for evaluating pilotage is extremely high.

2. SNI Flight Path Variation

Once the level of realism is determined to be acceptable, the results of the simulated flight path adherence can be gathered with a high degree of confidence. The variables of flight path variation that should be recorded for each instance of variation are: 1) duration of flight path deviation, 2) maximum distance of deviation, and 3) the aircraft flight aspect at the time of the deviation. The flight path variation results could be matched up against the airspace scenario in an effort to determine the cause of the variation. This result could potentially be used in future SNI route qualification training but is irrelevant to determining the appropriate separation minima criteria for developing SNI routes. For purposes of deciding how close SNI routes can safely be placed to fixed wing flight corridors, the cause of a path variation is of no concern, whereas the level of deviation is of primary concern.

LIST OF REFERENCES

1. Department of Transportation, Aviation Capacity Plan, Chapter 1, 1991.
2. Federal Aviation Administration Monthly Summary Air Traffic Activity and Delays in the National Airspace System (NAS) June 2000 - January 2001
3. FAA Order 7110.65N Air Traffic Control, pp2.1.1-3.1.3, Feb 2002.
4. FAA Order 7110.10 Aeronautical Information Manual Addendum, Pilot/Controller Glossary, Feb 2002.
5. www.jrotc.org/images/ClassDAir.gif
6. Title 14 Code of Federal Regulations-Chapter I-Part 91, Jun 2002.
7. Federal Aviation Administration Monthly Summary of Air Traffic Activity and Delays in the National Airspace System (NAS), January 2000-June 2001.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
Fort Belvoir, Virginia
2. Dudley Knox Library
Naval Postgraduate School
Monterey, California
3. Marine Corps Representative
Naval Postgraduate School
Monterey, California
4. Director, Training and Education, MCCDC, Code C46
Quantico, Virginia
5. Director, Marine Corps Research Center, MCCDC, Code
C40RC Quantico, Virginia
6. Marine Corps Tactical Systems Support Activity (Attn:
Operations Officer) Camp Pendleton, California